

Physico-Chemical and Microbiological Assessment of Surface Water Quality of a Himalayan Wetland Deoria Tal, India

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Abstract
The Water Quality Index (WQI) is considered as an important method to assess the water quality of a water body for its users. This study was carried out to assess the water quality of a Himalayan wetland Deoria Tal. Deoria Tal is one of the most important wetlands of the Garhwal Himalaya, India. It is the major destination for tourists, trekkers and local inhabitants. The water samples were collected for a period of one year during April, 2014 to March, 2015. In order to develop the water quality index samples were subjected to a comprehensive physico-chemical analysis of 20 parameters which include air temperature, water temperature, pH, conductivity, turbidity, dissolved oxygen, free CO_2, biochemical oxygen demand, total dissolved solids, transparency, total alkalinity, hardness, chlorides, sulphates, phosphates, nitrates, Calcium, Magnesium, Potassium and Sodium. The WQI was calculated and the value was obtained as 76.15. Most of the values of physico-chemical parameters are within the prescribed limits of WHO/BIS for drinking water. Water Quality Index (WQI) calculated based on the weight values of these parameters also revealed the ‘good’ quality of lake water. The α-diversity of microbes was found to be 18 in the water of Deoria Tal. The water of the lake is fit for human consumption. Keeping in view the importance of the lake and to provide the sustainable water quality for users its conservation and management is priority in the Himalayan region.
Keywords: Himalayan wetland; Deoria Tal; Garhwal Himalaya, Uttarakhand; water quality index; physico-chemical parameters

1. Introduction

Water is considered as one of the most important and valuable natural resources on the Earth, which is commonly shared by all the living beings residing on the planet ‘Earth’. India has various number of natural wetlands distributed unequally all over the country, but their presence in the Himalayan region has a great importance as these are the important source of freshwater for the local villagers, tourists, trekkers, sages and wildlife.

Wetlands are considered to be ecological barometers of the health of a region as they are playing an important role to regulate the micro-climate of any region Benjamin *et al*. [1]. The quality of surface water body has a direct and indirect effect on the groundwater level and its water quality. Wetlands are the inland water bodies which have a great importance for the society as they are the sources of water for various human activities as well as for drinking purpose of wildlife. The water quality of a surface water body is not only depend on the natural causes such as precipitation inputs, soil erosion, etc but also on the artificial causes such as urban, industries and agriculture practices Papatheodorou *et al*. [2]. The degradation of water quality due to various anthropogenic pressures has resulted in altered species composition and decreased overall health of water bodies Campbell *et al*. [3]; Durell *et al*. [4] and Ouyang *et al*. [5]. Natural wetlands are mostly found in the mountain region. The hydrologic status of water of any wetland in terms of quality and quantity is a result of multiple and complicated process of physico-chemical and biological inputs Singh *et al*. [6]. The physical inputs include air and water temperature, turbidity, etc. The chemical input consists of dissolved oxygen, biochemical oxygen demand, pH, chlorides, free carbon dioxide etc, while the biological features include fecal and total coliforms.

WQI is one of the aggregate values which is widely accepted as a rating that resembles the overall quality of the water Tiwari and Mishra [7]. A water quality index (WQI) helps in understanding the general water quality of any water body either it is natural or artificial, freshwater or marine water, either on hill region, ground water or surface water Samantray *et al*. [8]; Alam and Pathak [9]; Seth *et al*. [10]; Yadav *et al*. [11]. WQI is one of the most effective tool to assess the water quality of a water body (Kannan [12]; Mishra and Patel [13]; Naik and Purohit [14]; Pradhan *et al*. [15]; Alobaidy *et al*. [16] and communicates the information to the citizens and policy makers for the proper conservation and management of the water body.

Though some work has been done on different aspects of the wetlands. This include the work of Mustapha and Omotosho [17] on Moro wetland of Nigeria; Karafistan and Arik-Colakoglu [18] on Manyas wetland of Turkey; Singh *et al*. [6] on wetlands of western Himalaya; Ravikumar *et al*. [19] on Mallathalli wetland of Bangalore Urban district; Ramesh and Krishnaiah [20] on Bellandur lake of Bangalore; Lala *et al*. [21] on Himalayan wetland of Kashmir; Singh and Hussian [22] on groundwater of Greater Noida sub basin and Bouslah *et al*. [23] on water quality index assessment of Koudiat Medouar Reservoir, Algeria. But no work has been done so far on the water quality of the Deoria Tal. Hence, the present work has been carried out with a vision to assess the water quality by analyzing physico-chemical, biological parameters and the estimating water quality index. The obtained data on the water quality index of Deoria Tal of Garhwal Himalaya can be used by policy makers and wetland managers for its conservation and management.

2. Materials and methods

2.1. Study area

Deoria Tal is one of the most beautiful and important wetland having scenic beauty as well as valuable ecosystem services, located at an altitude of 2,445 m a.s.l. and between latitude $30^0$31'44" N and longitude $79^0$07'48" E. (**Fig.1**). This wetland is elliptical in shape with a length of 350 m and width of 150 m. The circumference of this wetland is around 605 m with a total surface area of 1.16 ha and a catchment area of 5.2 ha. (**Fig. 2**). The maximum depth of the wetland is 21 m. It can be visited by the tourists, trekkers and local inhabitants round the year. Mountains ranges such as Chaukhamba, Banderpunch, Kedar, Kalanag and Nilkanth are visible from the wetland. According to Hindu mythology, it is believed that the Hindu gods take bath in this wetland due to which it is named as Deoria Tal. This lake is also believed to be the Indra Sarovar referred in the Puranas. This lake has a mythological connection with the epic of Mahabharata, as it is believed that it is the same place where Yaksha asked the Pandavas to answer his questions before drinking the water of the lake. Every year the local villagers organize a religious fair near the lake on the occasion of Sri. Krishna Janmastami. Deoria Tal is located at a trekking distance of about 3 Km from the Sari village of Rudraprayag district of Uttarakhand. This wetland is elliptical in shape and medium in size and has no discernible inlet as well as outlet. Natural drains are the only source of water for the lake which is managed by the luxuriant vegetation around the lake. The lake is covered by the dense forest of various tree species. The dominating species are *Quercus leucotrichophora, Q. floribunda, Rhododendron arboretum, Myrica esculenta, Taxus baccata* and *Cedrus deodara* at top canopy, while the ground vegetation is dominated with *Robus ellpticus, Berbaris aristata, B. Asiatica* and *B. lyceum.*

2.2. Water sampling

The water of Deoria Tal was sampled for a period of April, 2014 to March, 2015. Water samples were collected from four different sites (S_1, S_2, S_3 and S_4) of the lake (Fig. 2.2) from surface water dipping the sterilized sample bottles 10 cm below water surface in the lake during 9:00 to 11:00 hrs. Some of the physico-chemical parameters required for water quality analysis like pH, air temperature, water temperature and dissolved oxygen were measured at each sampling site of the lake. For the microbiological sampling, water samples were collected from all the sampling sites and mixed all the samples thoroughly in the sample bottle and then placed it in the ice box filled with freezed ice packs and analyzed within 24 hours. For the analysis of remaining physico-chemical parameters and microbiological identification, the water samples were brought to Srinagar Garhwal by the earliest at its possible and analyzed in Laboratory of Freshwater Biology, Department of Environmental Sciences, H.N.B. Garhwal University (A Central University), Srinagar Garhwal, Uttarakhand, India. All the physico-chemical parameters and bacterial identification test were analyzed by following the standard methods outlined in Wetzel & Likens [24] and APHA [25]. Water samples from all the four sampling sites were analyzed for a predefined set of physical and chemical parameters to resemble that how these parameters and environmental changes affect the water quality. Water temperature was measured by dipping the digital thermometer 10 cm below surface in the lake carefully. The temperature range of digital thermometer was (-50 ^{0}C to +300 ^{0}C). pH was measured both at the site by using litmus paper and portable pH meter of Electronics India (Model No. 7011) and in the Laboratory by using the Toshcon Bench Top Multiparameter (Model No. TPC-17). Dissolved oxygen was measured by using the Modified Winkler method at the sampling site. Biochemical Oxygen Demand (BOD) was also measured by the standard method. Conductivity and total dissolved solids (TDS) were measured by using the Toshcon Bench Top Multiparameter (Model No. TPC-17). Free CO_2, total alkalinity, total hardness, Calcium hardness, chlorides and Magnesium hardness were measured by following the protocols available in APHA [25]. Nitrates, sulphates and phosphates were measured by spectrophotometric method by using the Systronic UV-VIS Spectrophotometer (model No. 117). Sodium and Potassium were measured by using Electronic India Flame Photometer (model No. 1385) following the given protocol in Wetzel & Likens [24] and APHA [25]. The statistical mean with standard deviation of all the replicates of the samples for each site was also calculated. Pearson's correlation coefficients between various physico-chemical parameters were also computed.

2.3. Water Quality Index (WQI)

WQI is an abyssal number that combines the various water quality values into a single number by normalizing values to subjective rating curves. All these parameters or characteristics occur in variable ranges and expressed in various units. The WQI takes the complex scientific information into a single number. For this purpose, fifteen water quality parameters were selected. Values used for each parameter were the mean value of the three sites of four replicates of each site. In the formulation of WQI, the 'standards' (permissible values of various parameters) for the drinking water used in this study were those recommended by the WHO (2004). The calculation and formulation of the WQI involved the following steps. Alobaidy *et al*. [16] :

First step: Each of the fifteen parameters has been assigned a weight (AWi) ranging from 1 to 4 depending on the collective expert opinions taken from different previous studies Prati *et al*. [26]; Ramakrishnaiah *et al*. [27]; Alobaidy *et al*. [16]; Sharma *et al*. [28] and Sharma and Kumar [29]. The mean values for the weights of each parameter have been shown in **Table 1**. However, a relative weight of 1 was considered as the least significant and 4 as the most significant.

Second step: The relative weight (RW) was calculated by using the following equation:

$$RW = \frac{AWi}{\sum_{i=1}^{n} AWi} \quad (1)$$

where, RW = the relative weight, AW = the assigned weight of each parameter, n = the number of parameters. The calculated relative weight (RW) values of each parameter have been given in **Table 2**.

Third step: A quality rating scale (Qi) for all the parameters except pH and DO was assigned by dividing its concentration in each water sample by its respective standard according to the drinking water guidelines recommended by the WHO, the result was then multiplied by 100.

$$Qi = [Ci / Si] \times 100 \quad (2)$$

While, the quality rating for pH or DO (Q_{pH}, DO) was calculated on the basis of,

$$Q_{pH}, DO = \left[\frac{Ci - Vi}{Si - Vi}\right] \times 100 \quad (3)$$

where, Qi = the quality rating, Ci = value of the water quality parameter obtained from the laboratory analysis, Si = value of the water quality parameter obtained from recommended WHO, Vi = the ideal value which is considered as 7.0 for pH and 14.6 for DO.

Equations (2) and (3) ensures that $Qi = 0$ when a pollutant is totally absent in the water sample and $Qi = 100$ when the value of this parameter is just equal to its permissible value. Thus the higher the value of Qi is, the more polluted is the water. Mohanty [30]

Fourth step: Finally, for computing the WQI, the sub indices (SIi) were first calculated for each parameter, and then used to compute the WQI as in the following equations:

$$SI\,i = RW \times Qi \quad (4)$$

$$WQI = \sum_{i=1}^{n} SIi \quad (5)$$

The computed WQI values could be classified as <50 = Excellent; 50-100 = Good; 100-200 = Poor; 200-300 = Very poor; >300 = Unsuitable. Prati et al. [26]; Ramakrishnaiah *et al*. [27]; Alobaidy *et al*. [16]; Sharma *et al*. [28] and Sharma and Kumar [29].

2.4. Microbial enumeration

Nutrient Agar media (HiMEDIA) was used for the estimation of the numbers of colony forming units (CFUs) of bacteria. Media pH for bacterial isolation was set according to the pH of sampling sites. Sabaroud Dextrose Agar (SDA) was used for fungal species. SDA media was supplemented with $50 mg.l^{-1}$ of each Streptomycin and Ampicilin to prevent bacterial contamination. Actinomycetes Isolation Agar (AIA) was used for actinomycetes isolation.

To study the morphological characteristics, the purified selected bacterial and archael isolates were Gram stained and observed under Phase Contrast Microscope (Nikon Eclipse TS100). Moreover, detailed biochemical characterizations were carried out to identify the isolates up to possible genus or species level. Identification of all the fungal isolates was made by microscopic analysis by using taxonomic keys and standard procedures.

3. Results and Discussion

3.1. Physico-chemical characteristics of water

The values of all the physico-chemical parameters were obtained from the analysis of water samples of Deoria Tal collected from four different sites of the lake throughout the year during April, 2014 to March, 2015. These values refer to the mean value of all the four sites along with minimum, maximum, mean and value of standard deviation of water samples collected in different months (Table 3).

3.1.1. Air and water temperature

Monthly variations in the mean values of air and water temperature were quite high. The air temperature ranged from 10.98^0C to 29.5^0C (Figure 3). The mean value of air temperature during the study periods was recorded 21.11^0C. However, the water temperature was recorded minimum (9.28^0C) in the month of January and maximum (26.68^{0}C) in the month of July (Figure 4). Similar observations were recorded by Singh and Laura [31] on Tilyar Lake, Karafistan and Arik-Colakoglu [18] on Manyas Lake, Sharma *et al.* [32] on Gokyo lake and Singh *et al*. [33] on Suraj Tal and Sisso lake in Himachal Pradesh. The water and air temperature are directly proportional to each other. Increase in the air temperature causes an increase in the water temperature.

3.1.2. pH

The pH or hydrogen ion concentration is considered as one of the most important factors that indicates the level of pollution. During the entire study, the water of the wetland was found slightly acidic. It ranged from 6.30 to 6.93 (Figure 5). The permissible range of pH for drinking water was specified as 6.5 to 8.5 as per WHO and BIS standards. The similar results on pH were observed by Ghimire *et al*. [34] on Gorekshep Lake, Pyramid Lake and Gokyo Lake.

3.1.3. Conductivity

Conductivity is the measurement of cations which greatly affects the taste of water. It is an indirect measure of total dissolved solids. Minimum conductivity (134.0 µS/cm) was recorded in the month of January and maximum conductivity (191.25 µS/cm) was recorded in the month of August (Figure 6). The permissible limit of electrical conductivity for drinking water as per WHO standards was less than 250µS/cm. Similar results on conductivity were observed by Bhat *et al*. [35] in Pengong Lake in Ladakh region.

3.1.4. Turbidity

Turbidity represents the clarity of the water. The measurement of turbidity in the water samples of a water body is a key test to assess the water quality. Turbidity and the intensity of scattered light are directly proportional to each other. It also means that as the turbidity of water increases, the amount of sunlight penetrates the water decreases. The concentration of turbidity was recorded minimum (1.90 NTU) in the month of January and maximum (7.68 NTU) in the month of August during the rainy month (Figure 7). The permissible limit of turbidity in the drinking water is up to 0.5 NTU as per WHO standards and 1.0 NTU as per BIS standards.

3.1.5. Dissolved Oxygen

Dissolved oxygen is considered as the most important parameter for assessing the health of a water body. It is considered as a direct indicator of water quality. The concentration of dissolved oxygen depends on the physical, chemical and biological characteristics of water body. The concentration of dissolved oxygen is inversely proportional to the temperature of the water body. Higher the temperature, lower is the dissolved oxygen in the water body. The concentration of dissolved oxygen was recorded minimum (6.6 mg/l) in the month of July and maximum (7.55 mg/l) in the month of September (Figure 8). The permissible limit of dissolved oxygen concentration for drinking water is more than 5. 0 mg/l as per WHO standards. Dissolved oxygen is the value that represents the quality of water and to evaluate the water of that water body is fit for consumption or not and the magnitude level of eutrophication; Edmondson [36]. Similar observation was recorded by Bhat and Pandit [37] from Wular Lake, a Ramsar site in Kashmir.

3.1.6. Free CO_2

Concentration of free carbondioxide is also considered as one of the important water quality parameters. Higher is the free CO_2 in the water body, higher is the pollution level in the water body. The minimum concentration (1.27 mg/l) of free CO_2 was recorded in the month of January and maximum (2.1 mg/l) was recorded in the month of August (Figure 9). The concentration of free CO_2 was much less than the permissible limit of WHO for drinking water which is 250 mg/l.

3.1.7. Biochemical oxygen demand

The biochemical oxygen demand (BOD) of the lake water of Deoria Tal ranged from 0.22 mg/l in the month of November and January to 0.36 mg/l in the month of June (Figure 10). It is the amount of oxygen consumed by the microbes during the incubation period. The permissible limit of BOD in drinking water as per WHO standards is 2.0 mg/l. Thus, the BOD of Deoria Tal water is under the prescribed limit.

3.1.8. Total dissolved solids

Total dissolved solids (TDS) refer to the minerals, salts, metals, ions and organic matter dissolved in the water. The minimum value (80.5mg/l) of TDS was recorded in the month of October and maximum value (114.5 mg/l) in the month of August (Figure 11). The recorded range was much less than the permissible limit of 600 mg/l for drinking water as per WHO standards. Similar results were observed by Bhat *et al*. [35] in Pengong Lake in Ladakh region and Singh *et al*. [33] in Deepak Tal of Lahaul-Spiti in Himachal Pradesh.

3.1.9. Transparency

Transparency is the depth of water up to which we can see in the water by our naked eyes. The concentration of TDS and turbidity is directly proportional to the level of transparency. The minimum transparency (33.75 cm) was recorded in the month of August which is due to the rainy month and maximum transparency (145.25 cm) in the month of January (Figure 12).

3.1.10. Total alkalinity

The total alkalinity was recorded minimum (10.53 mg/l) in the month of May and maximum (13.85 mg/l) in the month of October (Figure 13). The permissible limit of total alkalinity for drinking water is 200mg/l as per WHO and BIS standards. The similar results were recorded by Naik *et al*. [38] on high mountain lake, Kailash Lake of Jammu and Kashmir.

3.1.11. Hardness

The value of total hardness is the amount of salts dissolved in the water. It is mostly due to the presence of Calcium and Magnesium ions. The use of water can be decided by the concentration of hardness present in the water whether it is used for drinking purpose, irrigation purpose or industrial purpose. The rocks surrounding the water body is largely the source of hardness. The value of hardness in the water body during the study period ranged between 3.1 mg/l to 4.7 mg/l (Figure 14), which is much less than the permissible limit of hardness in the drinking water (200 mg/l) as per WHO and BIS standards.

3.1.12. Calcium and Magnesium

The concentration of Magnesium was recorded minimum (1.2 mg/l) in the month of March and maximum (2.13 mg/l) (Figure 15) in the month of June, whereas the concentration of Magnesium ranged from 0.44 mg/l to 0.63 mg/l (Figure 16). Both the concentrations of Calcium and Magnesium are much less than the permissible limit of Calcium (75 mg/l) and Magnesium (30 mg/l) for drinking water as per WHO and BIS standards.

3.1.13. Chlorides

The concentration of chlorides dissolved in the surface water mainly occurs naturally from the surroundings. The concentration of chlorides ranged between 1.92 mg/l and 4.68 mg/l (Figure 17), which is much lesser than the permissible limit of 250 mg/l for drinking water as per WHO and BIS standards. The similar range of fluctuations (4.25±0.03mg/l to 7.44±0.33 mg/l) in the concentrations of chlorides was found in different basins of Dal Lake of Kashmir Himalaya by Lone *et al*. [39].

3.1.14. Sulphates, Phosphates and Nitrates

The concentration of sulphates in the water samples of Deoria Tal ranged from 0.03 mg/l to 0.05 mg/l (Figure 18), whereas, the concentration of phosphates was recorded within a range of 0.01 mg/l to 0.04 mg/l (Figure 19). However, the concentration of nitrates in the water samples was recorded minimum (0.01 mg/l) in the months of July, November, February and March and maximum (0.04 mg/l) in the month of October (Figure 20). The concentrations of sulphates, phosphates and nitrates were recorded much less than the permissible limit of WHO and BIS standards for drinking water which 200 mg/l for sulphates and 45 mg/l for nitrates.

3.1.15. Potassium and Sodium

The mean value of concentration of Potassium was recorded minimum (0.22 mg/l) in the month of January and maximum (0.71 mg/l) in the month of August (Figure 21) whereas, the mean value of concentration of Sodium ranged from 0.54 mg/l to 0.96 mg/l (Figure 22)

3.2. Statistical treatment of data

The correlation coefficients of air temperature in relation with water temperature (r=0.993), turbidity (r= 0.918), hardness (r= 0.911), Calcium (r=0.908) and Potassium (r= 0.928) were found significant positive relationship. However, it was a negative relationship with transparency (r= -0.963) (P<0.001). The correlation coefficients of water temperature in relation with turbidity (r= 0.924), hardness (r=0.904), calcium (r= 0.889) and potassium (r= 0.922) was found significant positive relationship; but it was negative relationship with transparency (r= -0.957) (P<0.001). The correlation coefficient of conductivity showed positive relation with turbidity (r= 0.880) and free CO_2 (r=0.878), where (P<0.001). Turbidity showed a positive correlation with free CO_2 (r= 0.894) and negative correlation with transparency (r= -0.943) (P<0.001). The correlation coefficient of transparency showed a negative correlation with hardness (r=-0.914); Calcium (r=-0.929) and Potassium (0.967) with significance level (P<0.001). Hardness also showed positive correlations with Calcium (r=0.941); Magnesium (r=0.959) and Potassium (r=0.919) with signifinace level of P<0.001. Magnesium also showed a positive correlation with potassium (r=0.875) (P<0.001). Fecal coliform showed a strong positive correlation with total coliform (r=0.965) (P<0.001) (Table 4).

3.3. Water Quality Index (WQI)

The Water Quality Index (WQI) was used to accumulate diverse parameters and their dimensions in a single value, that displaying the water quality of Deoria Tal. It was observed from all the computed data for all the required water quality parameters that the value is **76.15**. Therefore the water of Deoria Tal can be categorized into “Good” during the sampling period. Detailed statistics for all the water quality examined during the assessment are shown in **Table 3**, while the correlation coefficients between the parameters are shown in **Table 4**. In order to reach better view on the water quality of Deoria Tal water, selected results from the physico-chemical parameters are presented in **Table 3**.

3.4. Microbial diversity of Deoria Tal

A total of six species of bacteria (*Diplococcus sp, Microbacterium scheliferi, Micrococcus sp, Paenibacillus azatofixans, Ralstonia eutropha* and *Staphylococcus sp*) and two genera of actinomycetes (*Streptomyces sp* and

Nocardia sp) were found in the water sample of Deoria Tal. However, ten genera of fungi (*Achlya, Aspergillus, Cladosporium, Curvularia, Isoachlya, Phoma, Saprolegnia* and *Verticillium*) were also found. The α-diversity of microbes was found to be 18 in the water of Deoria Tal (**Table 5**).

4. Conclusions

Water quality index is a unique method for the assessment and management of water quality. Most of the physico-chemical parameters of the water of Deoria Tal were within the range of drinking water recommended by WHO [40] and BIS. However, a few parameters were close to the permissible limits. The value of Water Quality Index (WQI) (76.15) computed after accumulating diverse physico-chemical parameters of the lake water confirms the good quality of the water of Deoria Tal. The α-diversity of microbes was found to be 18 in the water of Deoria Tal. Water of Deoria Tal is used by tourists, trekkers, local inhabitants, sages and wildlife for drinking purposes. Therefore, keeping in view the sustainable maintenance of water quality and its religious importance, the conservation and management of the Deoria Tal should be taken up on priority basis.

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Table 1. Assigned weight values of water quality parameters adopted from the literature (Prati *et al*.1971; Ramakrishnaiah *et al*. 2009; Alobaidy *et al.* 2010; Sharma *et al*. 2016 and Sharma and Kumar, 2017)

Parameters	Sampling sites				Mean value
	S_1	S_2	S_3	S_4	
Turbidity (NTU)	3	2	4	4	3.25
TDS (mg/l)	4	2	4	3	3.25
Conductivity(µS/cm)	3	3	2	2	2.5
Total alkalinity (mg/l)	3	2	3	2	2.5
Free CO_2 (mg/l)	3	3	3	3	3.0
DO (mg/l)	4	4	4	4	4.0
B.O.D. (mg/l)	4	3	4	3	3.5
pH	4	2	3	3	3.0
Chlorides (mg/l)	3	3	3	3	3.0
Total hardness (mg/l)	3	3	3	3	3.0
Nitrates (mg/l)	4	3	4	4	3.75
Sulphates (mg/l)	4	3	4	4	3.75
Sodium (mg/l)	3	3	3	3	3.0
Calcium (mg/l)	3	3	3	3	3.0
Magnesium (mg/l)	3	2	3	2	2.5

Table 2. Relative weight values of the water quality parameters of the Deoria Tal, Garhwal Himalaya

Parameters	Water quality standard (WHO)	Water Quality standard (BIS)	Assigned weight (AW)	Relative weight (RW)
Turbidity (NTU)	0.5	1.0	3.25	0.069149
TDS (mg/l)	600	500	3.25	0.069149
Conductivity(µS/cm)	250	N.A	2.5	0.053192
Total alkalinity (mg/l)	200	200	2.5	0.053192
Free CO_2 (mg/l)	250	N.A	3.0	0.063830
DO (mg/l)	5.0	6.0	4.0	0.085106
B.O.D. (mg/l)	N.A	2.0	3.5	0.074468
pH	6.5-8.5 (8.0)	6.5-8.5	3.0	0.063830
Chlorides (mg/l)	250	250	3.0	0.063830
Total hardness (mg/l)	200	200	3.0	0.063830
Nitrates (mg/l)	45	45	3.75	0.079787
Sulphates (mg/l)	200	200	3.75	0.079787
Sodium (mg/l)	200	N.A	3.0	0.063830
Calcium (mg/l)	75	75	3.0	0.063830
Magnesium (mg/l)	30	30	2.5	0.053192
Total			**47**	**1.0**

Table 3. Monthly variations in physico-chemical parameters of Himalayan wetland Deoria Tal, Uttarakhand from April 2014 to March 2015 (Mean value of all sites, minimum, maximum and mean±SD)

Parameters/Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Min.	Max.	Mean±SD
A.T	23.08	25.18	28.03	29.50	26.70	24.65	20.10	17.13	14.08	10.98	14.95	18.88	10.98	29.5	21.11±5.99
W.T	19.85	22.10	25.45	26.68	23.88	21.20	17.38	15.65	10.95	9.28	11.00	16.40	9.28	26.68	18.32±5.86
pH	6.90	6.93	6.85	6.73	6.58	6.53	6.90	6.50	6.53	6.30	6.33	6.40	6.3	6.93	6.62±0.23
Cond.	163.75	167.25	172.50	177.50	191.25	171.50	166.00	172.00	156.50	134.00	153.25	159.50	134	191.25	165.42±14.14
Turb.	4.90	5.20	5.84	6.90	7.68	6.35	5.78	3.90	2.30	1.90	2.20	3.93	1.90	7.68	4.74±1.91
D.O	7.15	7.10	6.80	6.60	7.30	7.55	7.15	7.40	7.30	7.35	7.30	6.95	6.6	7.55	7.16±0.27
Free Co_2	1.57	1.55	1.71	1.99	2.10	1.87	1.76	1.76	1.32	1.27	1.38	1.78	1.27	2.1	1.67±0.26
B.O.D.	0.28	0.31	0.34	0.36	0.26	0.26	0.24	0.22	0.24	0.22	0.24	0.24	0.22	0.36	0.27±0.05
TDS	87.00	88.25	96.25	95.00	114.50	95.50	80.50	93.75	89.75	81.75	94.25	90.50	80.5	114.5	92.25±8.72
T.P.	82.50	63.75	55.25	35.50	33.75	46.50	100.25	109.25	128.25	145.25	133.00	117.75	33.75	145.25	87.58±39.91
Alkal.	11.53	10.53	12.03	12.95	12.65	11.60	13.85	13.40	12.25	11.70	11.25	12.50	10.53	13.85	12.19±0.94
Hard.	4.30	4.50	4.55	4.70	4.60	4.00	3.40	3.20	3.30	3.20	3.10	3.10	3.1	4.7	3.83±0.67
Cl^-	2.74	3.55	3.59	3.40	4.51	4.26	3.97	4.68	4.61	1.92	3.27	2.95	1.92	4.68	3.62±0.83
SO_4^-	0.04	0.04	0.03	0.05	0.04	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.03	0.05	0.04±0.01
PO_4^-	0.01	0.01	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.03	0.02±0.01
NO_3^-	0.01	0.03	0.02	0.01	0.03	0.02	0.04	0.01	0.02	0.03	0.01	0.01	0.01	0.04	0.02±0.01
Ca	1.80	1.90	2.13	2.01	2.01	2.00	1.56	1.28	1.28	1.32	1.40	1.20	1.2	2.13	1.66±0.35
Mg^{2+}	0.61	0.63	0.60	0.63	0.61	0.50	0.46	0.47	0.49	0.44	0.45	0.46	0.44	0.63	0.53±0.08
K^+	0.56	0.60	0.59	0.70	0.71	0.62	0.35	0.43	0.39	0.22	0.28	0.37	0.22	0.71	0.49±0.17
Na^+	0.92	0.96	0.89	0.81	0.94	0.85	0.73	0.74	0.54	0.57	0.71	0.72	0.54	0.96	0.78±0.14

Table 4. Statistical correlation (correlation coefficients) computed between the physico-chemical parameters of water of Deoria Tal

	A.T.	W.T.	pH	Cond.	Turb.	D.O.	Free CO_2	B.O.D.	TDS	T.P	Alkal.	Hard.	Ca	Mg^{2+}	Cl^-	SO_4^-	PO_4^-	NO_3^-	K^+	Na^+
A.T.	1																			
W.T.	**0.993**	1																		
pH	0.667	0.662	1																	
Cond.	0.819	0.822	0.461	1																
Turb.	**0.918**	**0.924**	0.587	**0.880**	1															
D.O	-0.539	-0.553	-0.449	-0.228	-0.331	1														
Free Co_2	0.756	0.779	0.269	**0.878**	**0.894**	-0.279	1													
B.O.D.	0.832	0.822	0.634	0.467	0.589	-0.781	0.364	1												
TDS	0.490	0.481	-0.124	0.736	0.529	0.018	0.625	0.210	1											
T.P	**-0.963**	**-0.957**	-0.564	-0.852	**-0.943**	0.343	-0.786	-0.733	-0.592	1										
Alkal.	0.014	0.070	0.024	0.326	0.256	-0.156	0.488	-0.174	0.053	-0.009	1									
Hard.	**0.911**	**0.904**	0.669	0.678	0.798	-0.460	0.532	0.846	0.464	**-0.914**	-0.197	1								
Ca	**0.908**	**0.889**	0.622	0.665	0.830	-0.335	0.554	0.789	0.459	**-0.929**	-0.198	**0.941**	1							
Mg^{2+}	0.845	0.838	0.695	0.635	0.682	-0.521	0.430	0.838	0.418	-0.813	-0.236	**0.959**	0.822	1						
Cl^-	0.227	0.220	0.133	0.655	0.356	0.274	0.426	-0.062	0.490	-0.332	0.396	0.097	0.143	0.070	1					
SO_4^-	0.328	0.303	0.066	0.082	0.357	-0.337	0.328	0.324	-0.005	-0.324	-0.060	0.309	0.285	0.257	-0.421	1				
PO_4^-	0.462	0.459	0.069	0.618	0.623	-0.182	0.673	0.181	0.616	-0.523	0.442	0.338	0.374	0.225	0.472	0.081	1			
NO_3^-	-0.007	0.007	0.283	-0.009	0.205	0.210	-0.013	-0.132	-0.150	-0.076	0.088	0.091	0.164	-0.022	0.091	0.000	0.267	1		
K^+	**0.928**	**0.922**	0.549	0.854	0.870	-0.331	0.726	0.726	0.625	**-0.967**	-0.046	**0.919**	0.869	**0.875**	0.369	0.248	0.473	-0.058	1	
Na^+	0.852	0.839	0.639	0.719	0.779	-0.242	0.593	0.597	0.464	-0.824	-0.244	0.817	0.814	0.793	0.130	0.232	0.168	0.019	0.809	1

Table 5. Microbial diversity dwelling in the High altitude lake Deoria Tal, Garhwal Himalaya

S.No.	Microbes	Present/Absent
A	**Bacteria**	
1	*Diplococcus* sp.	+
2	*Microbacterium scheliferi*	+
3	*Micrococcus* sp.	+
4	*Paenibacillus azatofixans*	+
5	*Ralstonia eutropha*	+
6	*Staphylococcus* sp.	+
B	**Actinomycetes**	
1	*Streptomyces* sp.	+
2	*Nocardia* sp.	+
C	**Fungi**	
1	*Achlya* sp.	+
2	*Aspergillus* sp.	+
3	*Cladosporium* sp.	+
4	*Curvularia* sp.	+
5	*Isoachlya* sp.	+
6	*Phoma* sp.	+
7	*Saprolegnia* sp.	+
8	*Verticillium* sp.	+
9	*Alternaria* sp.	+
10	*Penicillium* sp.	+

Abbreviation +: Present

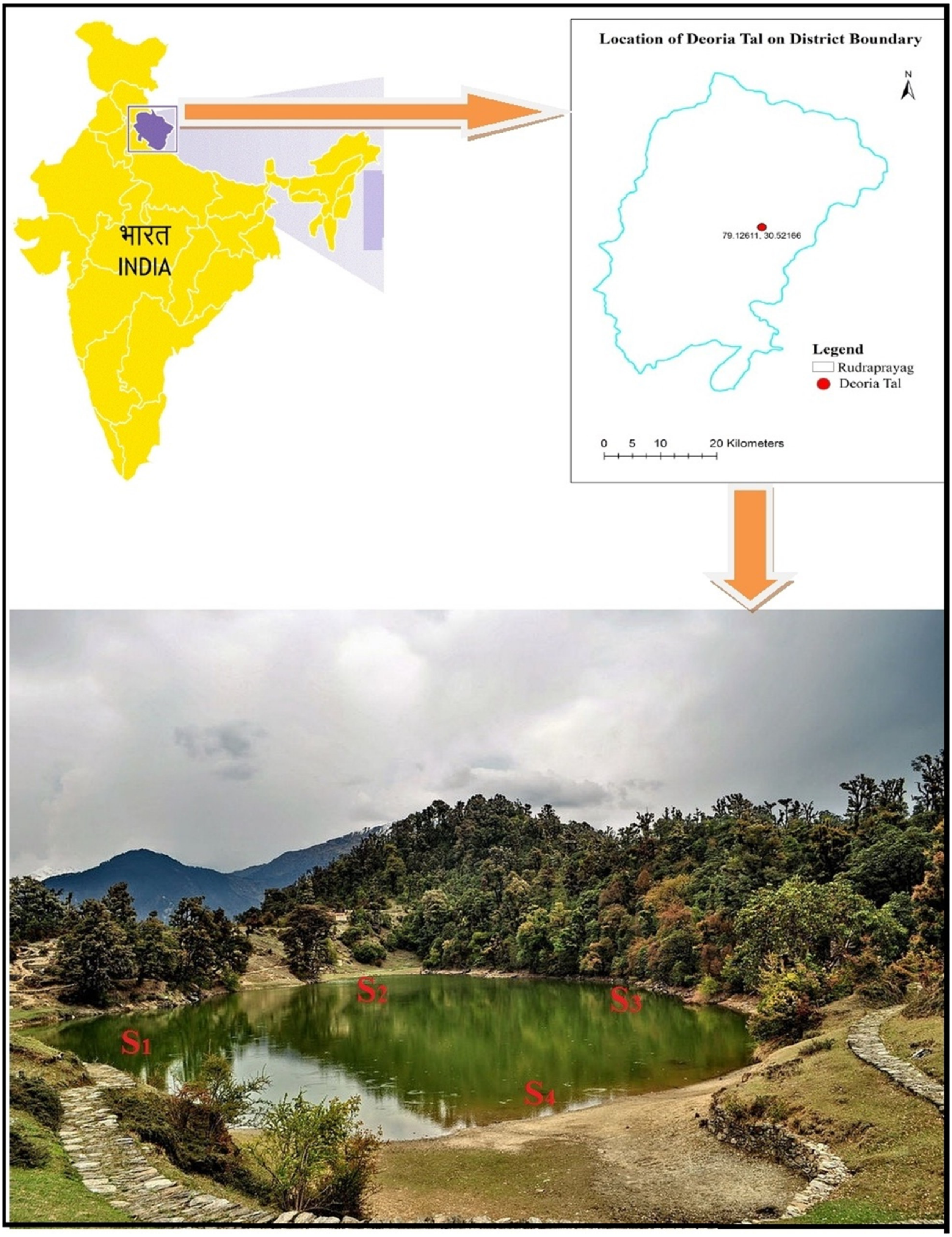

Fig. 1 The study area

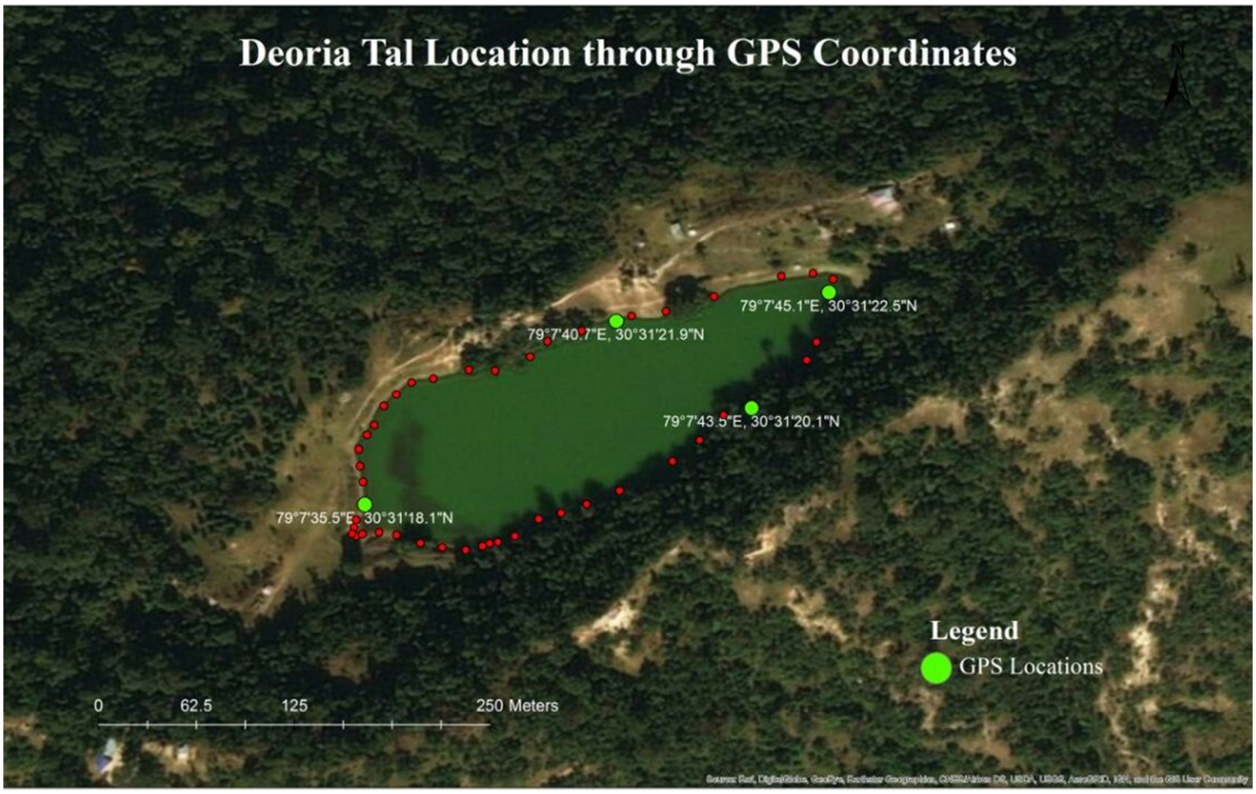

Fig. 2 Google map of Deoria Tal with GPS location of all the sampling sites (S_1-S_4)

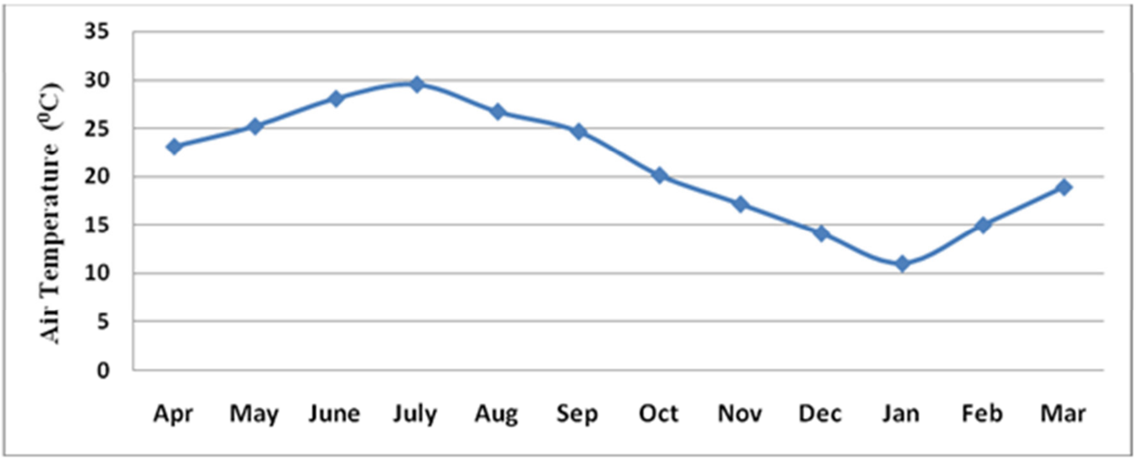

Figure 3. Monthly variations in air temperature

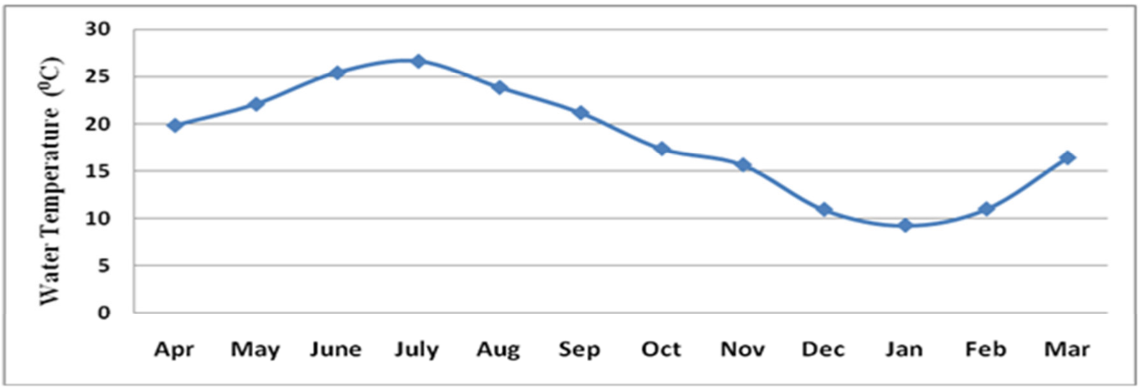

Figure 4. Monthly variations in water temperature

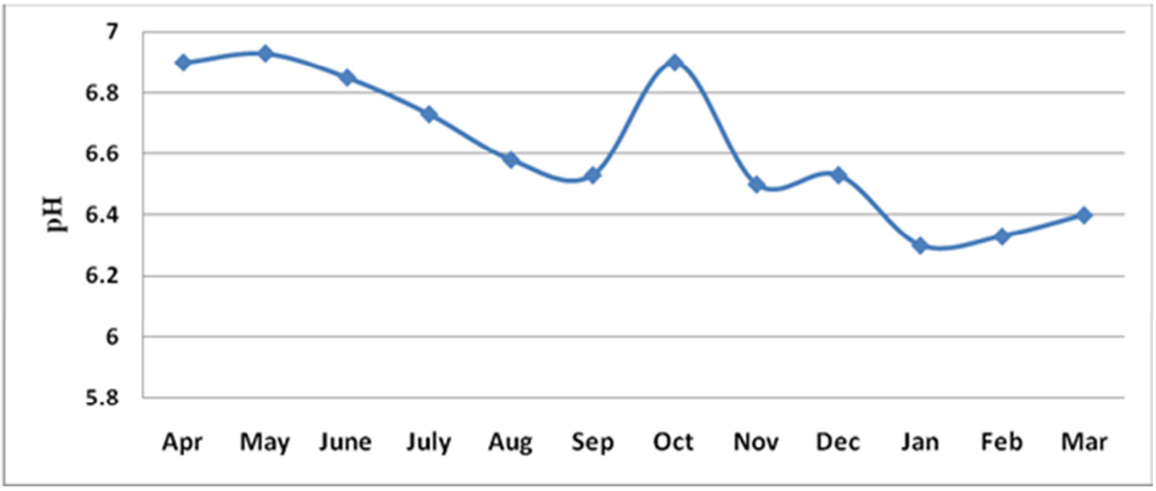

Figure 5. Monthly variations in pH

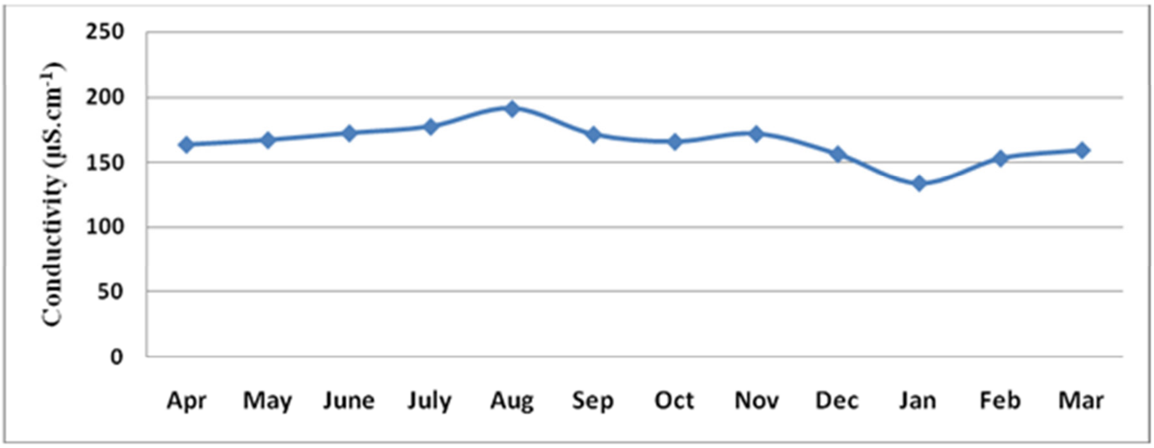

Figure 6. Monthly variations in conductivity

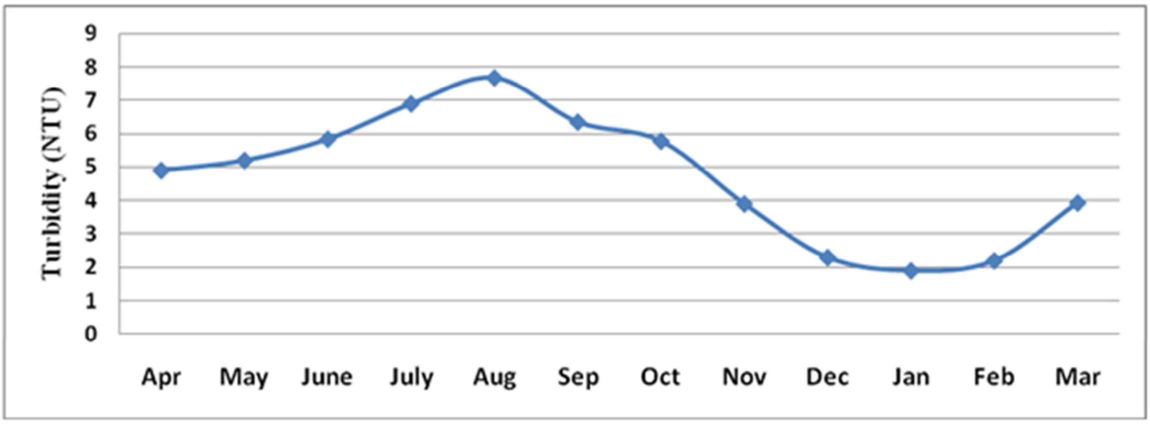

Figure 7. Monthly variations in turbidity

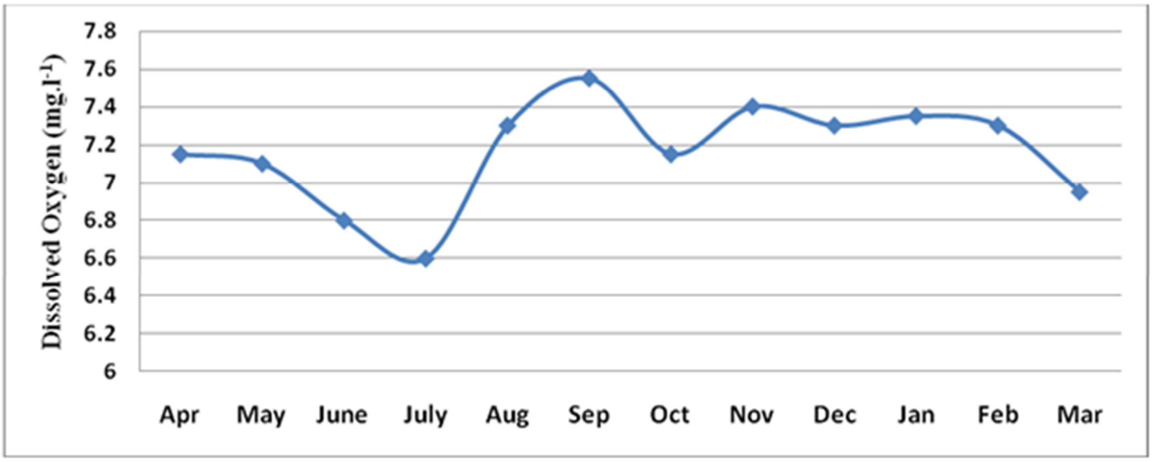

Figure 8. Monthly variations in dissolved oxygen

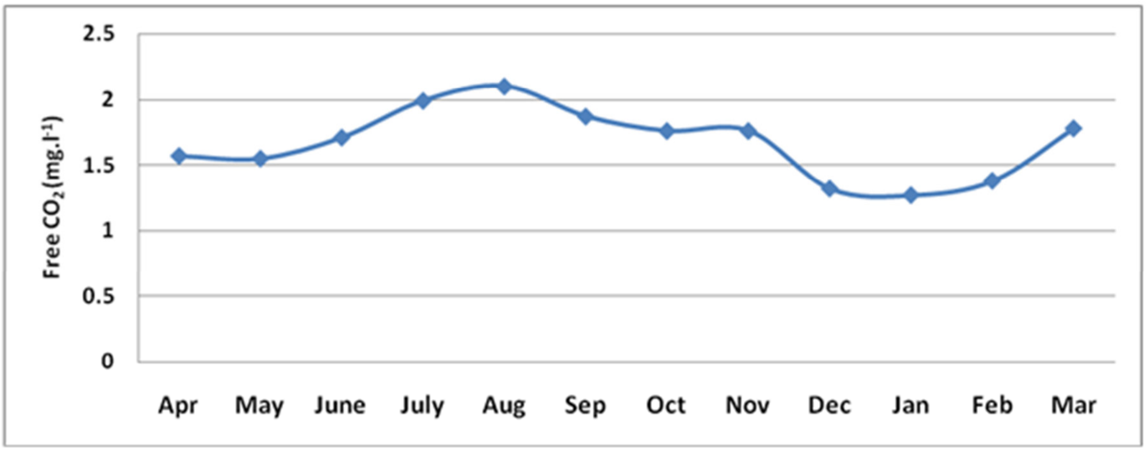

Figure 9. Monthly variations in free CO_2

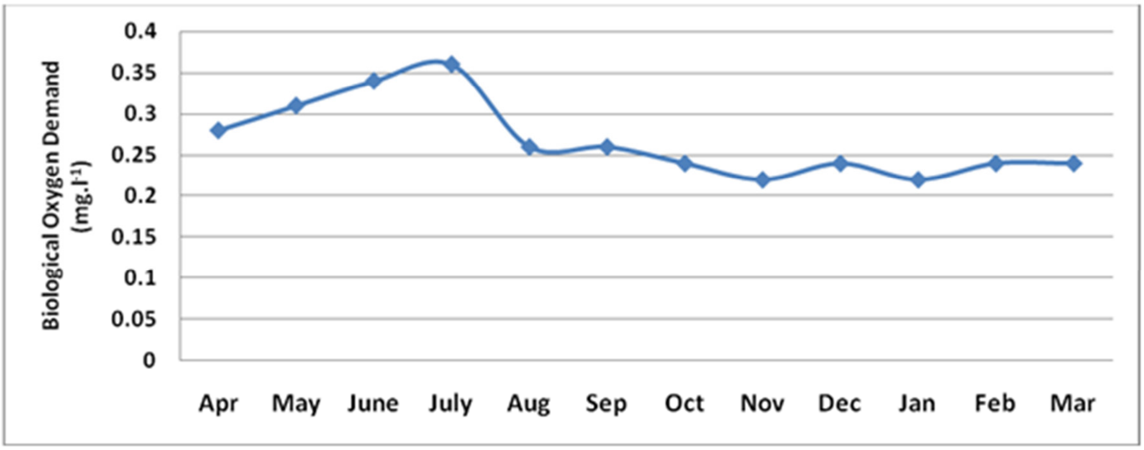

Figure 10. Monthly variations in biochemical oxygen demand

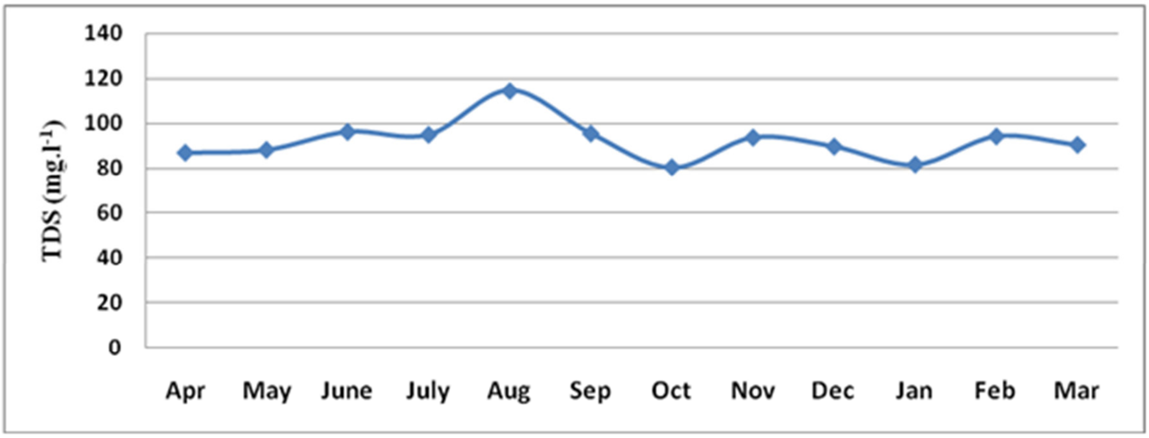

Figure 11. Monthly variations in total dissolved solids

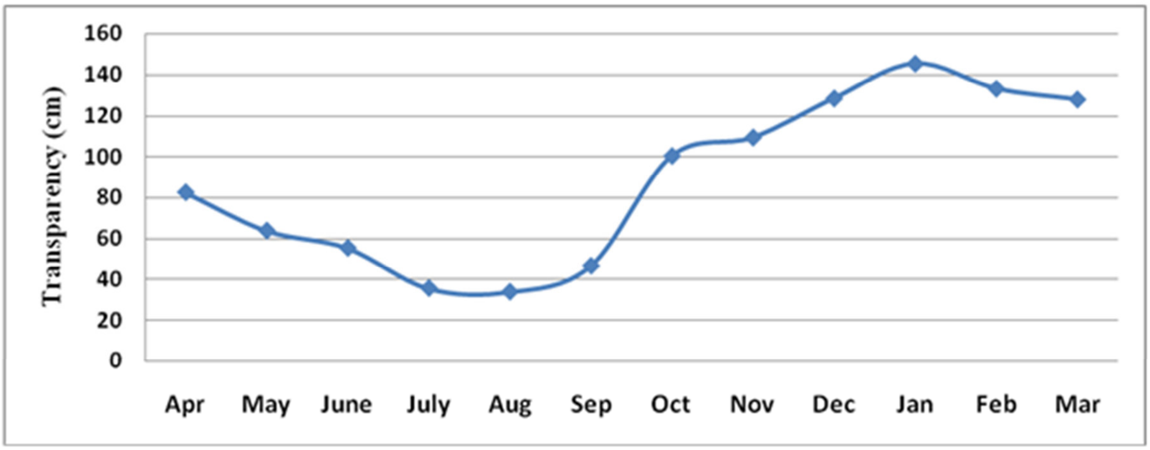

Figure 12. Monthly variations in transparency

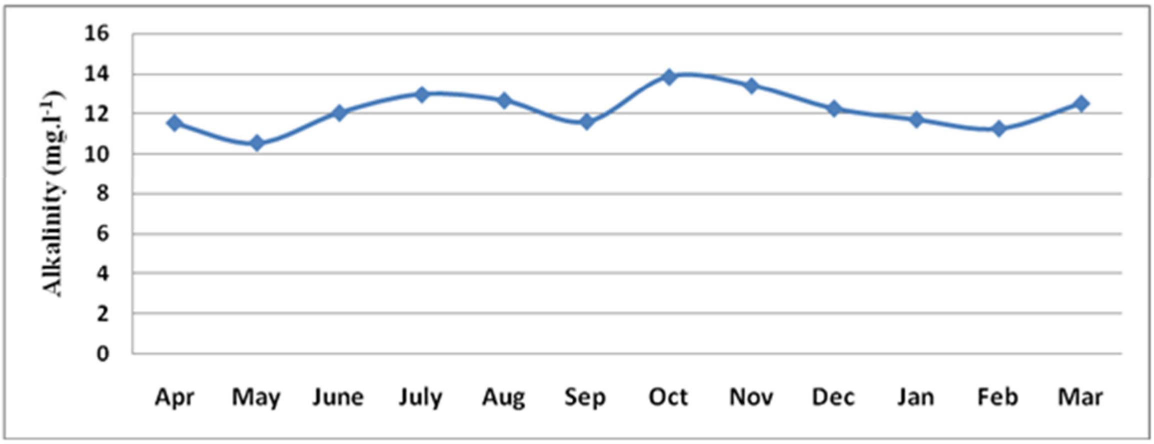

Figure 13. Monthly variations in alkalinity

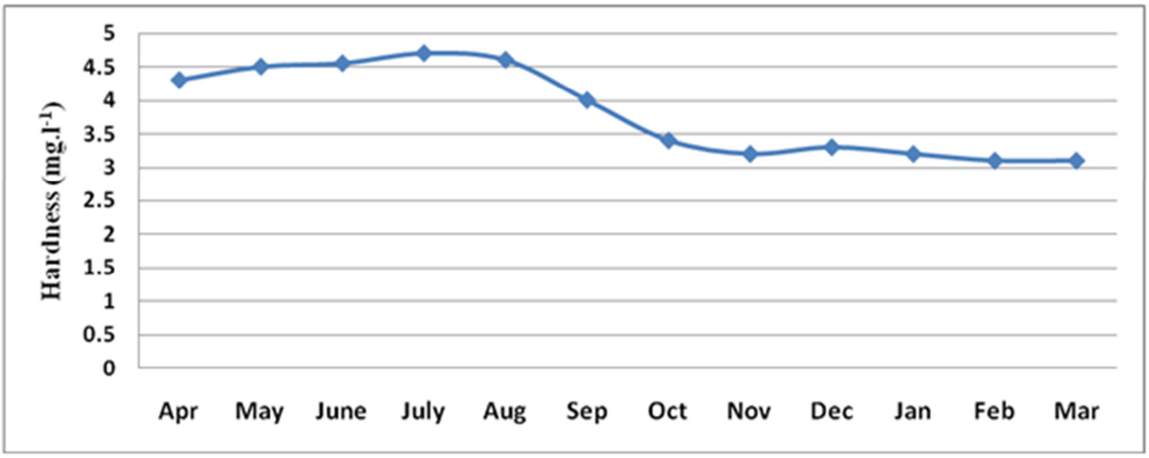

Figure 14. Monthly variations in hardness

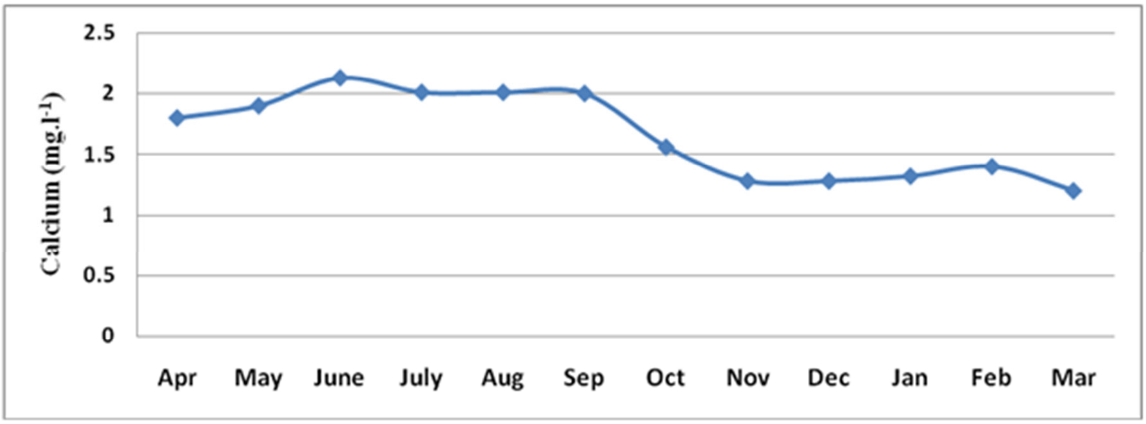

Figure 15. Monthly variations in calcium

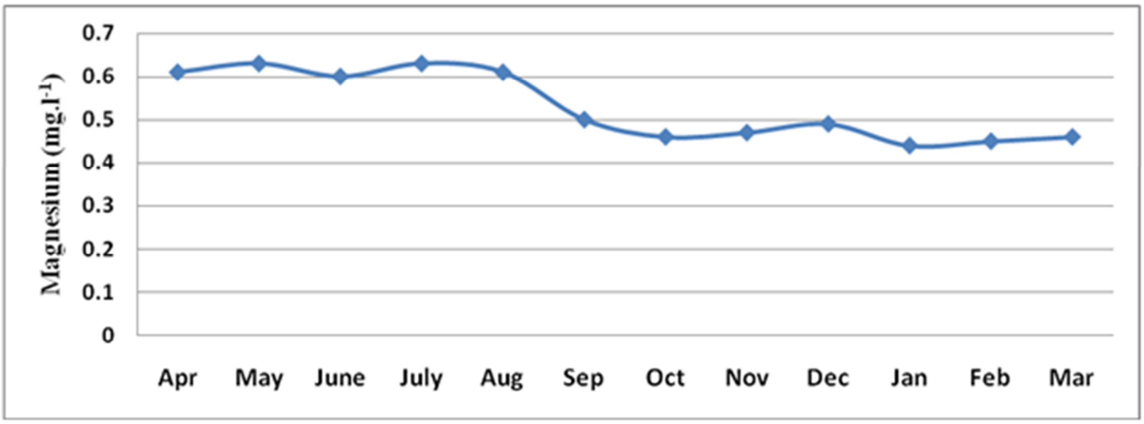

Figure 16. Monthly variations in magnesium

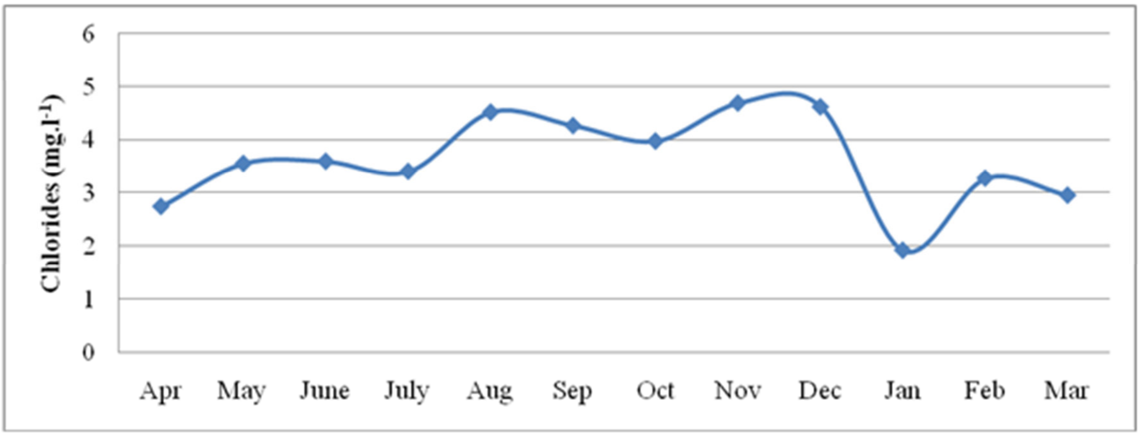

Figure 17. Monthly variations in chlorides

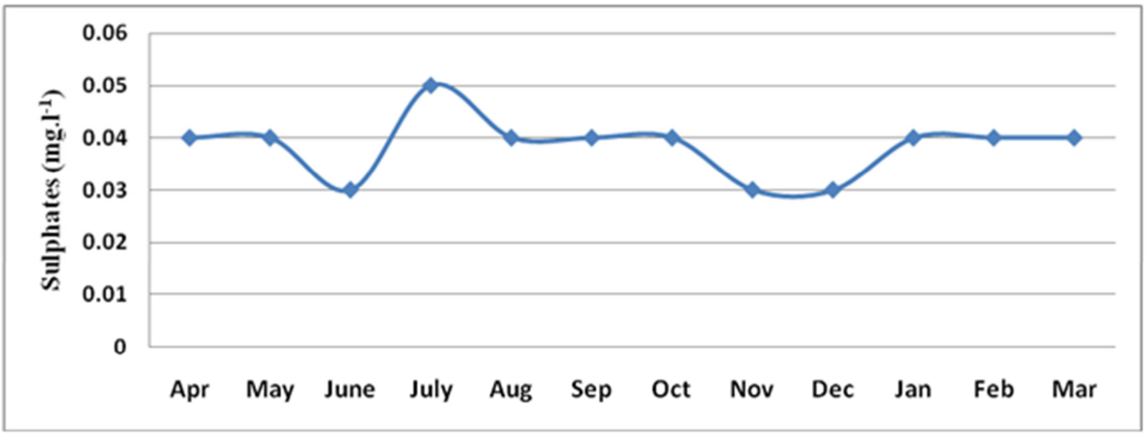

Figure 18. Monthly variations in sulphates

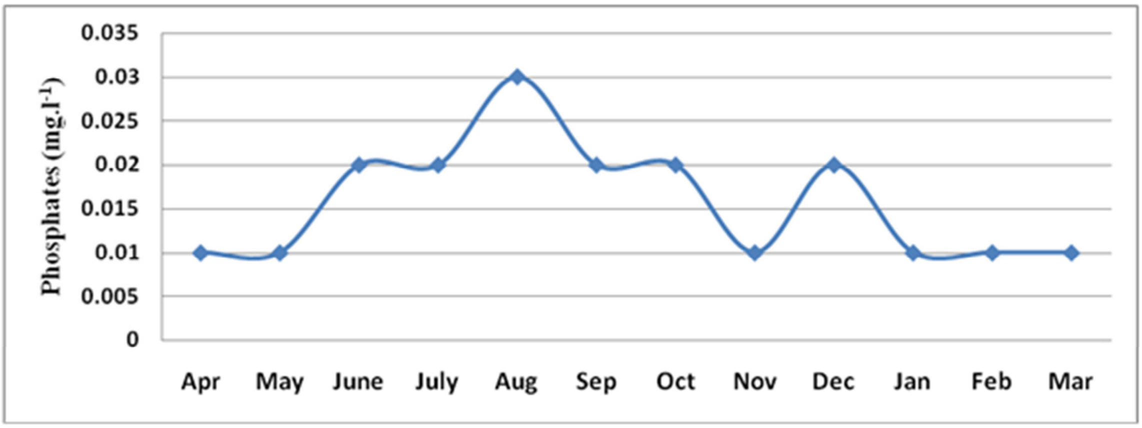

Figure 19. Monthly variations in phosphates

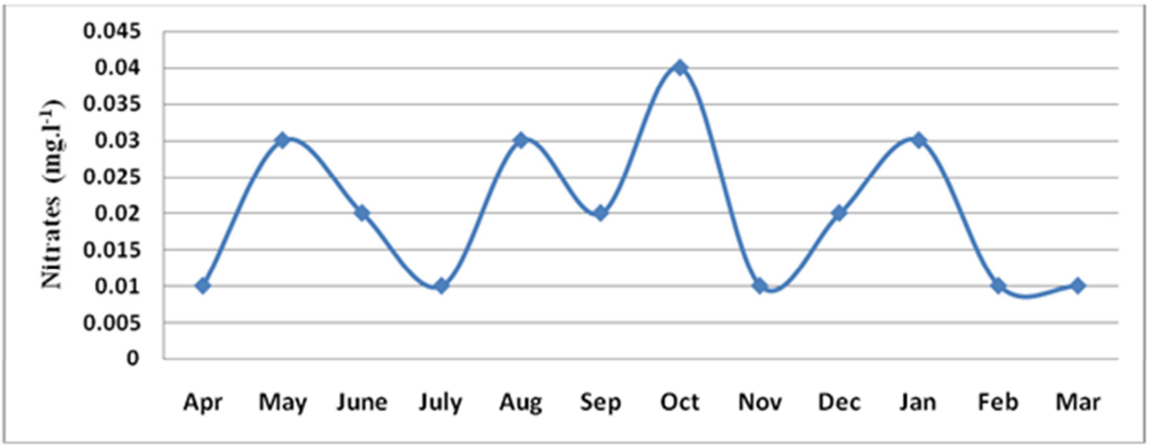

Figure 20. Monthly variations in nitrates

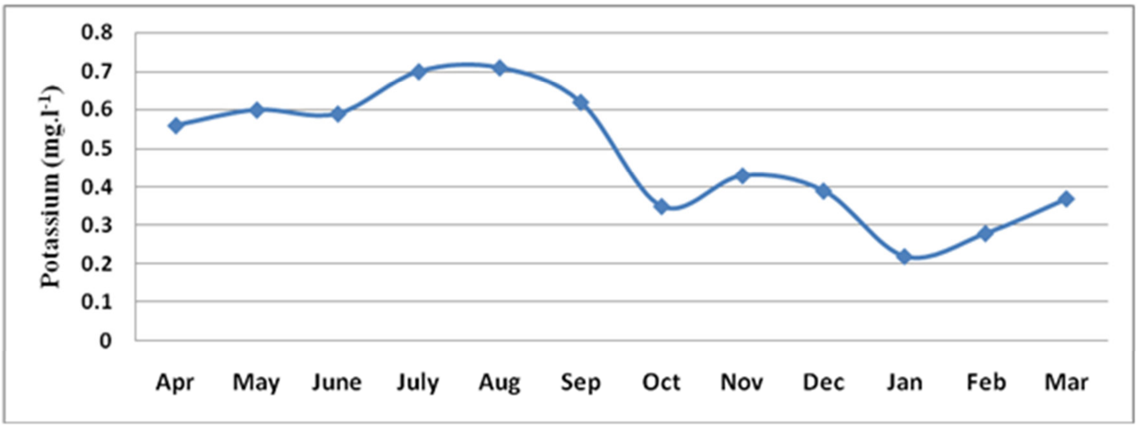

Figure 21. Monthly variations in potassium

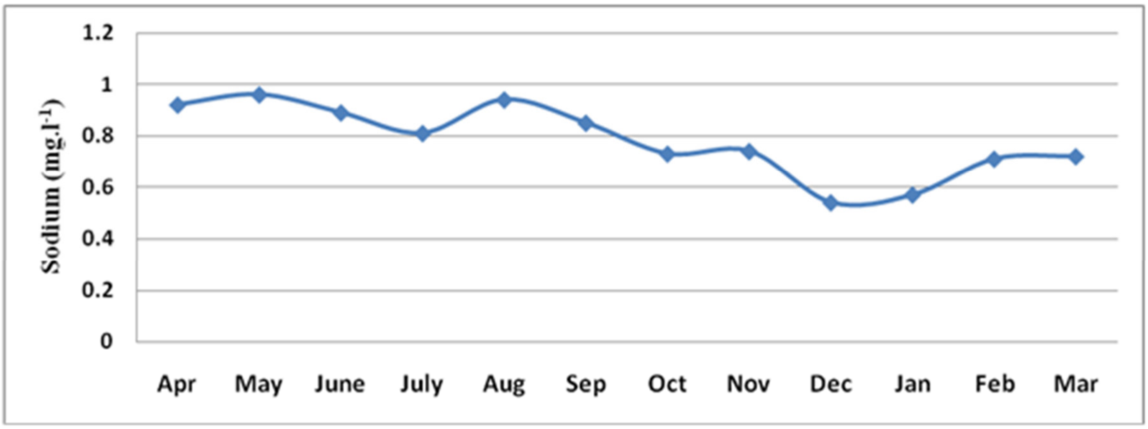

Figure 22. Monthly variations in sodium